

Summary of scientific experts panel

Background and organization

The purpose of the panel was to bring together scientists working in the field of fish nutrition, feedstuffs research, agriculture, biofuels, human nutrition, and byproducts processing to address a series of issues and questions regarding the future of alternative feeds for aquaculture.

Research panel members were asked to work on four specific tasks as they addressed the major topic areas:

1. Help answer the questions that the public submitted based on the Federal Register notice.
2. Identify constraints and possible solutions to the question of providing aquaculture feeds in the future as fish meal and fish oil become scarce.
3. Identify key research needs for moving forward.
4. Predict the future of aquaculture feeds, based on information gathered from the first three items in this list.

This panel provided the scientific foundation for addressing the critical issues affecting the future of aquaculture feeds and how they can be addressed. This panel also addressed how to get promising research results into commercial production. In all, 21 scientists from five countries (Australia, Canada, Japan, Norway, and the United States) participated for one and a half days of meetings held at NOAA's Northwest Fisheries Science Center, Manchester Lab, in Washington State.

The workshop facilitated discussion by the whole group in five sessions focused on the following subtopics:

- Public perception, public ideas, and education needs.
- Nutrient and feedstuffs constraints and possible solutions.
- Economic and environmental impacts from alternatives.
- Human health implications of alternatives.
- Research and technology transfer needs.

Each session was approximately 3 hours long and started with a quick review of any public comments received from the Federal Register notice germane to the session at hand. This was followed by several 5-minute mini-presentations by two to five members of the panel with specific expertise in the session topic designed to stimulate and frame the discussion. Mini-presentations were followed by a moderated discussion by the whole panel. A note taker recorded key points on display paper. At the end of the discussion, panel members were invited to prioritize points recorded during the session on the display paper by placing colored adhesive dots next to the points they considered most important. Each individual panel member was given 10 dots to use to highlight discussion points and was instructed to make

decisions independently. This information was used to ensure that the most important issues, solutions, and approaches were recorded.

At the end of the discussions, each panel member was assigned the following “homework” designed to provide a set of visions for the future of feeds for aquaculture:

The Future of Aquafeeds . . .

This is a take home assignment – each participant should send in within two weeks following the meeting, what they see happening in the next 5 and 25 years in the area of feeds for aquaculture. This is an exercise in science fiction so please take your best guess and use your imagination but be honest in what you really see as the future of aquafeeds. Please keep each Scenario (5 years from now and 25 years from now) to under 2 pages in length. As much as possible make them applicable to your location and species. Let us know what the diets will be composed of, what the feed efficiency and growth rates will be and what breakthroughs occur to make your scenarios possible. Where will the limiting nutrients come from and what feedstuffs will dominate the industry in your country? What species will these diets be fed to? How much aquafeed is being produced worldwide? How are these diets sustainable in the long run? You are welcome to also put in natural disasters which might affect aquafeeds.

The results of this assignment and similar responses from the stakeholder experts panel meeting are summarized in the section titled “Futurecasts from experts panels” on page 65.

Summary of scientific experts panel

Background and organization

The discussions resulting from these sessions tended to range across subtopics, alternatives, processes, approaches, research needs, roles of governments, technology transfer, and commercial development. While this sort of open discussion was productive at generating ideas and information, it complicated organizing this report chronologically. Instead, we captured the discussion according to feedstuffs and their potential for economic, environmental, and human health performance in aquaculture diets, regardless of which discussion group was involved—shown in Table 1. Likewise, we captured the discussions on research and practical approaches to resolving issues surrounding fish meal and fish oil replacement in Table 2.

Table 1.
Production, economic considerations, environmental considerations, human health implications, and potential barriers to expanded use of alternatives to fishmeal and fish oil in diets for aquaculture.

Feedstuff class	Suggested by: Public, Panel, or Both	Current annual production (tons)	Economic and practical considerations		
			Cost \$US/ton	Advantages	Disadvantages
Plant products	Both	~230 million metric tons	Generally between \$500–\$1800/metric ton	Low cost	Incomplete nutrients
				Biotechnology can keep costs down and improve nutrients to be complete	Anti-nutrients are costly to remove
				Largest quantity of proteins and oils on the earth from plants	High in carbohydrates which are costly to remove
Byproducts of bio-energy production	Both	For ethonol production at the end of 2008: ~26 million metric tons/year; by the end of 2015 will be between 30 and 40 million metric tons/year	Generally between \$100 to \$200 per metric ton	Low cost	Plant protein concentrates which work well for fish feeds are more expensive than fish meal
				Use of carbohydrate fraction for bio-energy may increase availability of the protein and bring costs down	Quality of protein sometimes low due to ethonol production process
					Lipid competes with biodiesel

Table 1

GLOSSARY

ALA	Alpha-linolenic acid (18:3n-3)
ANF	Anti-nutritional factors
ARA	Arachidonic acid (20:4n-6)
BSE	Bovine spongiform encephalopathy
CLA	Conjugated linoleic acid (18:2n-6)
DDGS	Distillers dried grain and solubles (byproduct of ethanol production)
DHA	Docosahexaenoic acid (22:6n-3)
EPA	Eicosapentaenoic acid (20:5n-3)
FM	Fish meal
FO	Fish oil
HUFA	Highly unsaturated fatty acids
LCn-3FA	Long chain omega-3 fatty acids (mostly EPA and DHA)
N	Nitrogen
OMP	Oregon moist pellet
P	Phosphorus
PBM	Poultry byproduct meal
PCB	Polychlorinated biphenyls
POP	Persistent organic pollutants
PPA	Plant Products in Aquafeeds Working Group
PUFA	Polyunsaturated fatty acids
SDA	Stearidonic acid (18:4n-3)

Environmental considerations		Human health/product quality considerations		Barriers to expanded use in aquafeeds
Advantages	Disadvantages	Advantages	Disadvantages	
Low trophic level; primary producers	Issues associated with increased agriculture	Can increase LCn-3FA by bio-technology	Naturally low in LCn-3FA	Sometime poor palatability
Can be organically produced, but will lack LCn-3FA		May contain phyto-chemicals that have positive implications for human health	May have contamination loads from farming practices (i.e. pesticides)	Can be high in anti-nutrients and carbohydrates
Coproduct provides use of waste material for another industry (e.g., starch)			May contain phyto-chemicals that have negative implications for human health	Greater processing trends to improve results with fish
Sequesters CO ₂				R&D plan well documented by plant products in aquafeeds working group; should use a model for other feedstuffs where applicable
Helps make biofuels more cost-effective to increase chance for replacement of fossil fuels	Issues associated with increased agriculture	May contain phyto-chemicals that have positive implications for human health	May have contamination loads from farming practices or processing for fuels	Byproducts (DDGS) and some protein concentrates from bio-diesel have poor functional qualities, high levels of indigestible material, and often poor protein quality; perhaps look at fractionation of protein before distillation or refining; variability in nutrient content, quality, and physical properties; transportation and storage challenges; sometimes poor palatability
Coproduct provides use of waste material from another industry			May contain phyto-chemicals that have negative implications for human health	
Sequesters CO ₂			No LCn-3FAs	Need to work with refining process to produce higher quality byproducts for aquafeeds

Results

Table 1
(continued)

Feedstuff class	Suggested by: Public, Panel, or Both	Current annual production (tons)	Economic and practical considerations		
			Cost \$US/ton	Advantages	Disadvantages
Rendered animal products	Both	~8 to 10 million metric tons	\$500 to \$800/metric ton	Use of waste material and established processes	Public concerns over BSE have resulted in restrictions on use in feeds
Byproducts from fishery and aquaculture (fish and shellfish)	Both	~2 million metric tons (already counted as fish-meal)	Same as fish meal from forage fish; \$1200–\$1600/ton	Easy to replace fish meal and oil with high quality meal	Expensive to capture
				High palatability	Located in small quantities from diverse sources Highly perishable until dried
Algae products (seaweeds)	Both	~1.5 million metric tons (dry); mostly for human and ruminant feed market	Depends on grade, species, and market; cost of algal protein concentrates or lipids have not yet been determined	May contain high levels of nutrients not found in terrestrial plants (LCn-3FA's, Taurine, etc.)	Low in protein and oils; would require significant processing to concentrate nutrients for fish
				No need for fresh-water or land	Little grown in the US Competition for use as human food
Krill or wild zooplankton	Both	~120,000 metric tons wet or 35,000 metric tons dry	\$2000 to \$3000/ton; can be higher for human food grades	Easy to replace fish meal and oil with high quality meal	Expensive to capture
				High palatability	Located in polar regions far from where needed Highly perishable until dried
Insect Products	Both	Less than 50,000 metric tons	Variable products on the market are higher than fish meal (up to \$10,000/metric ton)	High quality protein and oil	High levels of non-protein nitrogen (chitin)
		Mostly produced for high value pet market (birds and reptiles)		In theory, increased production would drop price below fish meal costs	

Results

Table 1
(continued)

Environmental considerations		Human health/product quality considerations		Barriers to expanded use in aquafeeds
Advantages	Disadvantages	Advantages	Disadvantages	
Recycles animal processing wastes back to fish	Issues associated with animal production	May be a source of CLA	Some markets do not allow terrestrial animal proteins BSE issue is unclear No LCn-3FAs and high in other less healthy fats	Some regulatory issues due to BSE; Poultry byproduct meal is widely used already and regulated by costs and supply
Uses waste which is now discarded, often causing nutrient pollution		High in LCn-3FA and other nutrients	May have the same contaminants as conventional fish meal and oil	Difficult to process due to the temporal and spatial availability of the wastes, and their perishable nature Costs currently higher than production of fish meal and oil from industrial fishery High costs for infrastructure, drying, and transport
Low tropic level; primary producers	Requires space	May be good source of LCn-3FAs and other marine nutrients		Protein and lipids need to be concentrated (carbohydrates removed) before feeding to canivorous fish
Can be used to reduce and sequester CO ₂ and nutrients from the ocean				Land or sea area needed for algae culture is either expensive or difficult to obtain permits in US Production is low and costs of production too high
Low on the food chain and selected species may support larger harvests	Suffers same issues as wild fisheries—is limited and can be overfished, etc.	May be good source of LCn-3FAs and other marine nutrients	May have the same contaminants as conventional fish meal and oil	Contains high levels of fluorine which may need removal
Represents the largest animal biomass on earth.	Supports other marine fauna and at the base of the food chain			Highly perishable needs to be processed within hours of capture
Current MSY target harvest level is higher than actual harvest level				Largely in international waters
Can be produced from diverse waste materials			No LCn-3FAs	May contain high levels of fluorine which may need removal High levels of chitin can result in poor functional qualities and low digestibility

Results

Table 1
(continued)

Feedstuff class	Suggested by: Public, Panel, or Both	Current annual production (tons)	Economic and practical considerations		
			Cost \$US/ton	Advantages	Disadvantages
Single celled protein/lipids	Both	Less than 50,000 metric tons	Variable products on the market are higher than fish meal	Grown on low cost nutrients Maybe a good way to produce limiting nutrients or special molecules for aquafeeds	Typically highly capital, infrastructure, technology, and energy intensive
Marine invertebrates	Both	Less than 50,000 metric tons	Variable; products on the market are higher than fish meal	Can be grown on fish wastes and low cost feeds	Neither culture systems nor wild harvest are developed
		Mostly used for bait or a part of a specialized feed		Typically highly palatable to some fish; may have higher value as a palatability enhancer	Wild invertebrates may harbor pathogens and parasites to fish Cost to rear in captivity is high
Invasive species meals	Both	Unknown	Unknown and variable	May be able to generate funds for capture as well as for product	Highly variable materials (green crabs, Asian carp, zebra mussels, etc.) so considerations will differ for each type of material
				Same advantages as fishery by-products	Successful project would work it's way out of a source of product Same disadvantages as fishery byproducts
Aquaculture of fish for fish-meal	Public	Unknown	Unknown	Could be a large supply not subject to limits and variations of wild populations	Likely very high cost to produce

Results

Table 1
(continued)

Environmental considerations		Human health/product quality considerations		Barriers to expanded use in aquafeeds
Advantages	Disadvantages	Advantages	Disadvantages	
Minimal direct impact to environment due to highly intensive and efficient systems		Can be a source of LCn-3FAs;		Production is low and costs of production too high
Recycles fish solids to a useful product	Wild harvest may be difficult to regulate	May be good source of LCn-3FAs and other marine nutrients	Some shellfish can contain toxins which might be passed up the food chain	Development of inexpensive culture systems
Low on the food chain	Wild harvest may remove an important part of the near shore ecosystem			Testing as a palatability enhancer to increase utilization of other more abundant but less palatable alternatives
Provides additional incentive to remove invasive species		May be good source of LCn-3FAs and other marine nutrients if marine species are used	No LCn-3FAs if freshwater species	Difficult to process due to the temporal and spatial availability of the material, and it's perishability; however processes do exist to make a high quality meal from this material; high costs for infrastructure
			May have the same contaminants as conventional fishmeal and oil	Highly variable material and often difficult to harvest cost effectively
May reduce use of fish meal and oil from capture fishery by direct substitution	Increased use of land or ocean space Would still require feeds and a source of LCn-3FAs and other limiting nutrients	May be good source of LCn-3FAs and other marine nutrients if marine fish	No LCn-3FAs if freshwater fish	No such marine systems exist Fish produced in aquaculture are suitable for higher value human market

Results

Table 2

Table 2.

Research and practical approaches to resolving issues surrounding fishmeal and fish oil replacement.

Issue	Approach	Options to achieve
General issues		
Lower the costs of alternative feedstuffs relative to FM and FO—the majority of alternatives are more expensive than FM and FO.	Improved sustainability must show economic benefits or a higher willingness to pay	<ul style="list-style-type: none"> • Research and technology improvement for alternatives • Communications and outreach with latest information • Industry should be responsible for technology development at some point—government should set limits • Need for clear administrative authority (NOAA/USDA) • Identify requirements for developing industry
Understand the environmental impacts associated with alternatives	Conduct environmental review studies	<ul style="list-style-type: none"> • Include review of environmental impacts of all feedstuffs in assessments • Compare to industrial fisheries and alternatives • Develop low pollution diets (N and P) by studying metabolism and absorption of feedstuffs in assessments
Maintain the human health value and eating quality of aquacultured seafood	Need LCn-3FAs for fish and higher levels for humans in final product	<ul style="list-style-type: none"> • Blend plant oils with fish oil or feed fish oil as finishing diet • Biotechnology-engineer plants to produce EPA and DHA • Develop low cost production of EPA and DHA from Algae and/or marine microbes • Recover more fish oil from byproducts of fish processing (wild and aquaculture) • Identify additional positive bioactive compounds in fish meal/fish oil • Beyond EPA/DHA—what are roles of SDA and other fatty acids in humans. • In oil replacement studies check taste, fatty acid levels and product quality • Need standard method to analyze for fatty acids in fish
	Reduce or eliminate contaminants	<ul style="list-style-type: none"> • Need to check for other contaminants as alternatives are used (e.g. pesticides in plants) • Monitor and keep dioxin/PCB levels low • Blend oils or filter oils to remove compounds
	Evaluate new ingredients for potential hazards	<ul style="list-style-type: none"> • Approach depends on alternative
	Conduct human health studies	<ul style="list-style-type: none"> • Link what goes in to fish to what is on plate • Studies in human populations eating fish fed alternative diets.
	Product quality	<ul style="list-style-type: none"> • Check flavor, texture and sensory qualities of fish fed alternatives • Should be low cost and abundant final product to increase consumption to healthy levels
Understand and manipulate the animals needs	Nutrition studies	<ul style="list-style-type: none"> • Improve diets for different life stages and new species • Need basic understanding of how fish use nutrients • Determine what semi-essential nutrients are in FM/FO that are needed by aquaculture organisms • Determine semi-essential nutrient levels that optimize performance (e.g. taurine)
	Genetic studies	<ul style="list-style-type: none"> • Species x nutrient interactions • Understand and use genetic diversity in cultured organisms
	Fish health studies	<ul style="list-style-type: none"> • Testing alternatives for impacts on health and intestinal morphology
	Fish physiology studies	<ul style="list-style-type: none"> • Improve our understanding of nutritional physiology in fish • Increase nutrient retention • Understand food allergies in aquaculture organisms • Determine how fish metabolize fatty acids—fates of ALA, EPA, DHA, SDA, etc

Results

Table 2
(continued)

Issue	Approach	Options to achieve
	Fish physiology studies (continued)	<ul style="list-style-type: none"> • Determine if ARA is an anti-nutrient and it's role in inflammation • Explore use of n-3 FA's as biomarkers. • Develop finishing diets and models of fat metabolism
	General	<ul style="list-style-type: none"> • Do longer term studies in fish
Pellet quality needs to be maintained		<ul style="list-style-type: none"> • Understanding functional properties of ingredients • Understand impacts on texture and palatability of pellets
Understand the impacts of climate change on feed-stuff quantity and quality	Approach depends on alternative	<ul style="list-style-type: none"> • Increase effort to develop those alternatives that may increase under climate change scenarios
Research and development needs to be increased and improved	<p>Improve support, usefulness, and efficiency of research</p> <p>Develop a database with info in one place</p>	<ul style="list-style-type: none"> • Need for long term funded research • Scientific collaboration • Industry involved • With cost, composition and formulation information
Improve communication with human nutrition community	<p>General</p> <p>Develop a Risk/benefits model for aquaculture products</p>	<ul style="list-style-type: none"> • Publish in Journal of Nutrition and trade publications • Attend and present at human nutrition conferences • Develop and populate a risk/benefit model for fish consumption with data from farmed fish
Education and outreach to consumer and public needs to be increased and improved	<p>Conduct human health studies</p> <p>Demonstrate benefits of farmed and wild fish consumption</p> <p>Conduct economic studies</p> <p>Increase visibility of aquaculture</p> <p>Flavor of product for humans maintained</p> <p>Cost to consumer needs to be low</p> <p>Market issues with alternatives need to be understood and addressed</p>	<ul style="list-style-type: none"> • Conduct a "lightning rod" study to demonstrate benefits • Address public perception of value of pills vs. food • Highlight positive role of fish in diet of children. • Highlight seafood's role in fighting obesity • Conduct breakeven/willingness to pay studies. • Ensure consistent and stable source of supply of feedstuffs • Demonstrate sound economic models • Understand timing of when products are available • Increase public relations efforts • Attend meetings outside of aquaculture area. • Get aquaculture and fisheries working together. • Reverse perception that aquaculture products are unhealthy • Put aquaculture scientists on USDA grant panels. • Demonstrate nutritional benefits of aquaculture products • Partner with food scientists and human nutritionists • Partner with economists and business experts • Partner with social scientists
Improve processing options to improve quality and reduce costs		<ul style="list-style-type: none"> • Investigate technologies to improve feedstuffs in general • Develop low cost/low energy methods to dry and stabilize meals • Increased use of air classification

Results

Table 2
(continued)

Issue	Approach	Options to achieve
Issues specific to different alternatives		
Increase the use of plant based feedstuffs	Plant protein concentrates price needs to drop	<ul style="list-style-type: none"> • Improve technology and develop industry. • Improve crop and coproduct consistency and quality
	Follow the PPA strategic plan (Options taken directly from from goals of the "Plant Products in Aquafeed Working Group Strategic Research Plan")	<ul style="list-style-type: none"> • Establish standardized research approaches and protocols for systematic evaluation of plant feedstuffs across carnivorous fish species • Enhance fish germplasm and discover genes • Enhance the inherent composition of crops to provide a beneficial balance of bioactive compounds in order to optimize their use in aquafeeds for carnivorous fish • Increase understanding of interactions between gastrointestinal microflora and plant tolerance in fish • Improve and optimize ingredient processing, feed manufacturing technology and feed formulations to increase inclusion of plant-derived ingredients in the diets of carnivorous fish • Optimize the storage, nutritional and sensory quality of aquaculture species for human consumption • Develop an international communications network for research on optimizing plant products in aquafeed
	Understand plant composition as it relates to fish requirements	<ul style="list-style-type: none"> • Determine what is missing in plants • Conduct taurine supplementation (and other semi-essential nutrients) and metabolism studies to improve plant based feeds
	Enhance plant fatty acids	<ul style="list-style-type: none"> • Use biotechnology
	Enhance plant proteins and products	<ul style="list-style-type: none"> • Improve processing • Use conventional plant breeding • Use biotechnology • Determine all the anti-nutrients in plants • Cure induced enteritis in salmonids
Increase the use of bioenergy coproducts	Develop high value molecules from plants	<ul style="list-style-type: none"> • Engineer plants to express carotinoids, etc.
	Increase economic and nutritional value of coproducts	<ul style="list-style-type: none"> • Examine processes and develop alternatives that produce higher quality coproducts • Protein research • Fiber research • Improve digestibility of DDGS • Improve crop and coproduct consistency and quality
Increase the use of marine algae	Develop high value compounds first.	<ul style="list-style-type: none"> • Investigate as a taurine source • Improve economics of DHA/EPA production by algae • Develop and improve fractionation techniques to increase protein/reduce fiber contents
	Develop easy methods to concentrate proteins and lipids	<ul style="list-style-type: none"> • Investigate enzymatic processing to concentrate protoplasts/reduce fiber contents • Investigate mechanical processing to concentrate protoplasts/reduce fiber contents
Increase the use of sustainably harvested krill and zooplankton		<ul style="list-style-type: none"> • Support ecosystem-based management of fisheries for feedstuff production • What is harvested for feed should be low on tropic level for increased biomass • Determine benefits and risks associated with a fishery for krill
Increase the use of cultured marine invertebrates		<ul style="list-style-type: none"> • Explore economic and nutritional value of cultured zooplankton meal (e.g. rotifers) • Explore economic and nutritional value of cultured invertebrate meal (e.g. Polychetes)

Feedstuffs

It is noteworthy that the cost per unit of protein for fish meal and per unit long chain omega-3 fatty acid (LCn-3FA) for fish oil is low relative to alternatives (Table 1). It is also clear that when a substitute provides a cost advantage to the overall diet without affecting performance it is quickly adopted by feed manufacturers. Indeed, a modern commercial salmon diet that may contain 30 percent fish meal is already 70 percent something else. Research, development and technology transfer that can help reduce the costs of abundant alternatives relative to fish meal and fish oil will likely result in quick incorporation into commercial diets.

One metric that may be a good predictor of future substitution potential is the amount of the protein or oil source available on the world market and its price. Typically, world market production and price are inversely correlated to a certain extent. The major protein sources are shown graphically in Figure 3 and the major oil sources in Figure 4. Ranges for this information are also given in Table 1. Clearly, much of the world's supply of protein and oil comes from plants. Plants already supply the majority of the protein and oil found in feeds for aquaculture, and this trend will likely continue. Plant products specifically mentioned by the panel include soy, canola (rape), corn, wheat, cottonseed, lupin, sunflower, flax linseed, and peas. Protein and oil concentrates, and gluten meals made from these crops would be the most useful for aquaculture, while the carbohydrate fraction is not useful.

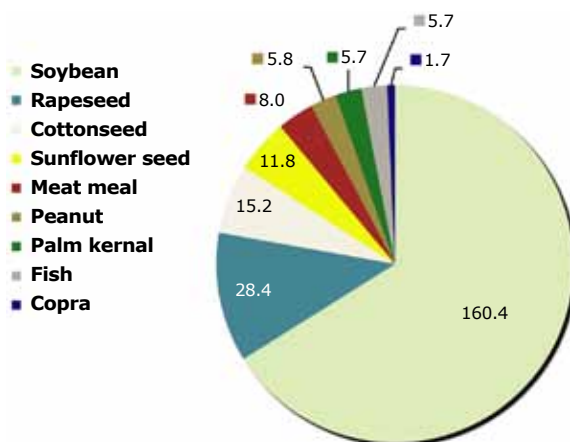


Figure 3
World production of
protein meals in 2007
(millions of metric tons)

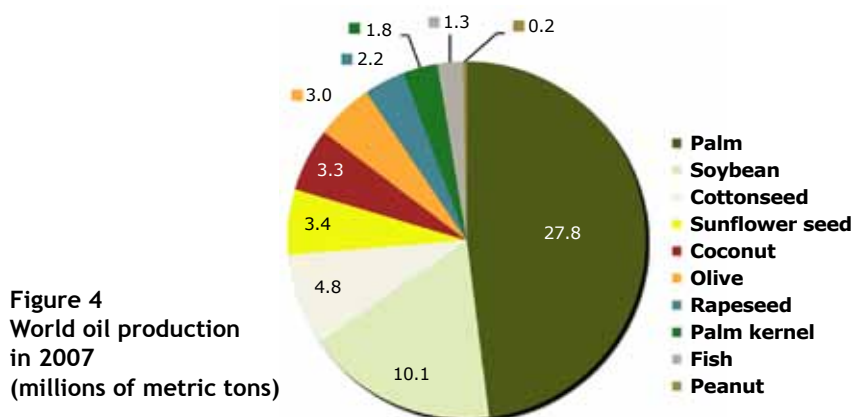


Figure 4
World oil production
in 2007
(millions of metric tons)

Results

Since biofuel production for alcohol, and bio-plastics production for degradable plastics, utilizes the carbohydrate fraction of plants to make ethanol and other molecules, there was a lot of interest in the potential synergies between these industries and feedstuffs for aquaculture. Biodiesel production uses the oil fraction of plants, but this could create high protein concentrates as by-products that could suit aquaculture diets. Since the bio-energy and bio-plastics industries are likely to be orders of magnitude larger than aquafeeds in the foreseeable future, the panel recommended working with these industries to ensure high-quality protein and oil by-products that would be suitable for aquaculture feeds.

Prior to this initiative, an ad hoc group of researchers formed the Plant Products in Aquafeeds Working Group (PPA). This group has published a review paper (Gatlin et al. 2007) a strategic plan (Barrows et al. 2008), and a tactical plan (<http://www.aquafeed.com/ppa-about.php>) focused on increasing the use of plant products for aquaculture feeds. Much of this is directly applicable to the NOAA/USDA Alternative Feeds Initiative. The scientific panel reviewed and endorsed the approach and planning by the PPA in their strategic plan, and those suggestions have been incorporated in Table 2. There are also extensive comments from the PPA available on line in the public comments page (<http://aquaculture.noaa.gov/news/comment.html>).

Other feedstuffs considered include byproducts of the fermentation industry (especially distillers dried grains and solubles—DDGS), byproducts from the capture fishery and aquaculture, algae, krill, zooplankton, insects, single celled protein (SCP—mostly yeasts and bacteria), marine invertebrates (mollusks and polychaetes), rendered animal products (mostly poultry byproduct meals), and invasive species meals. An additional suggestion made by the public was to rear species by aquaculture as a source of fish meal for aquaculture. The economic, environmental, and human health implications of these alternatives are summarized in Table 1 along with some of the challenges they present for fish feeds.

Nutrients

To a certain extent it was difficult to separate the discussion of nutrients from the discussion of the feedstuffs that contain them. However the need by fish for specific nutrients, rather than for any one feedstuff per se, provided some clear focus. In terms of identifying key nutrients, two classes of nutrients were identified as key to the future of feeds for marine aquaculture—long chain omega-3 fatty acids (LCn-3FAs) and compounds that are known and unknown in fish meal and fish oil that act as semi-essential nutrients (for example taurine, perhaps cholesterol, hydroxyproline, phospholipids, and others). In addition, the levels of known essential nutrients that might need to be adjusted due to protein and oil substitutions (such as vitamins

and minerals) that change either the requirement or bioavailability of these nutrients, needs to be investigated.

Two LCn-3FAs occurring in seafood—eicosapentanoic acid (EPA) and docosahexanoic acid (DHA)—are well known for their human health benefits. The panel repeatedly emphasized the importance of maintaining levels of these fatty acids in the products of aquaculture, primarily for human consumption and secondarily for fish, since fish tend to require a lower level than that which would be optimal for human health. Currently, the majority of LCn-3FAs in aquaculture diets are obtained from fish oil. However, forage fish do not make these fatty acids themselves but rather concentrate them through the food chain. The primary producers of these fatty acids in nature are marine algae and microbes. Two basic approaches to reducing reliance on fish oil for EPA and DHA were described:

1. Alter the feeding approach by growing fish on low LCn-3FA diets and use a “finishing” diet to boost these fatty acids at the end of the production cycle, thereby making the use of fish oil and other oils containing EPA and DHA more efficient.
2. Produce DHA and EPA from primary producers (algae and/or other marine microbes) or genetically modified plants, fungi, or microbes, and then replace some or all of the fish oil with blends of the alternative oils in the diet.

The panel agreed that both approaches should be investigated. The functional role of additional long chain fatty acids in fish oils are unknown but should also be investigated.

For the second class of nutrients identified by the panel—the semi-essential nutrients that are found in fish meals and fish oils but perhaps not in all alternatives—the approach suggested is to first identify all of them and then find ways to replace them. For this discussion, a semi-essential nutrient is one that is not needed for growth and survival per se, but is required for maximum growth rate, disease resistance, or other performance traits desirable in aquaculture. Repeatedly used as an example was taurine, a sulfur-containing amino acid not found in plants but abundant in animal tissue. The addition of taurine to plant proteins to make a higher performing diet is not difficult and abundant sources of taurine exist from animal by-products, some algae, and synthetic sources. However, the story of taurine illustrates the possibility that other semi-essential nutrients may not have been discovered, but may be lacking in alternative feed ingredients. The panel urged further research to discover additional semi-essential compounds so they can be incorporated into aquaculture diets.

The opposite issue pertains to anti-nutrients that may be abundant in alternative feed ingredients. Anti-nutrients are compounds that negatively impact the health or nutrition of the consuming animal. There are many anti-nutrients in plants, which have evolved to con-

tain these compounds as a defense against grazers. An example is trypsin inhibitor found in soybeans that allows them to pass through an animal's gut less digested and able to germinate. While plants are the classic example of meals containing anti-nutrients they are also found in other types of meals. Many of these anti-nutrients are broken down by heat or removed in the processes used to concentrate protein. The panel recommended further work on identifying and developing efficient processes to remove or destroy anti-nutrients in feed ingredients.

Looking beyond the practical and economic considerations of various feedstuffs, the panel also considered the environmental footprint of potential substitutes. Environmental impacts associated with feedstuffs were discussed in general terms for classes of feedstuffs from two points of view; 1) the environmental impacts associated with procuring it and 2) the environmental impacts of using it.

All of the proposed potential protein and oil sources could be sustainably developed to some extent. Wild harvest of algae, krill, zooplankton, and worms, as well as the processing of wild fish trimmings, still relied on good management of a wild resource, but generally represented the harvest of organisms lower on the food chain than traditional fish meal resources, or were from organisms already harvested for human consumption. The culture of algae and plants for feedstuffs presents an opportunity to increase supply beyond the limits of wild production by the application of aquaculture and agriculture; the former requires not much more than ocean surface area and management, whereas the latter requires all the inputs common to agriculture. Both primary producers have the added environmental benefit of capturing carbon. Culture of insects and marine worms provides an opportunity to produce protein and oils from materials fed to these organisms that would otherwise be discarded. The use of materials from bio-energy and bio-plastics provides the additional benefit of helping to improve the economics of those industries that can reduce reliance on fossil fuels. The use of rendered animal products and fish trimmings from aquaculture and wild harvest would help recycle high-quality protein and oil and keep this material out of landfills or the environment. Invasive species meals would also provide incentive to remove an invasive species, with presumed ecological benefits to the invaded ecosystem; however, the likely goal of such a program would be to reduce the supply of this material over time to very low levels, making its long-term economic future uncertain. Single-celled proteins and oils can be grown on very simple substrates and may be practical to supply key limiting nutrients or bioactive compounds that would enable the use of other alternative feedstuffs in aquaculture feeds.

The primary considerations for the environmental impacts of feeding alternative feedstuffs once the diet is complete are the changes in the amount of nitrogen (N), phosphorous (P), and/or solids produced by

fish fed alternative feeds. Since this concern is different depending on the nature of the receiving water and the types of feedstuffs used, it needs to be considered within context. Dietary nutrient efficiency should be investigated as promising dietary changes are discovered. The panel urged review of the environmental impacts of alternative feedstuffs relative to industrial fisheries and studies to understand impact to N and P metabolism and solids production.

The final area of consideration for substitutions was their impact on the quality of the product. Product quality for fish produced for human consumption has two components: 1) the impact on the health of the consumer, and 2) the impact on the taste, texture, and look of the product as food. Both areas were considered important, but the panel focused most of its attention on the first component. Fish are a healthy choice for human consumption because they contain essential and high-quality protein, oil, minerals, and vitamins. While all of these areas require monitoring to some extent when substitutions are made, it is primarily the oil and oil-soluble vitamins that can be altered due to diet. Therefore, the majority of the panel discussion focused on the oil fraction. Within the oil fraction, the majority of interest was on the n-3 fatty acids. On the other side there was discussion on the need to reduce potential contaminants such as methylmercury and PCBs (and other persistent organic pollutants—POPs). Alternatives generally have the potential to reduce the heart-healthy n-3 fatty acids unless specific attention is paid to including EPA and DHA in the diet. On the other hand, many of the alternative feedstuffs are lower in contaminants than fish oils. One consideration for plant meals is to examine the impacts of residual pesticides used in the farming of the replacement plant meal. Specific recommendations are presented in Table 2.

Alternatives to fish meal and fish oils have already come a long way. For example, in the 1960s diets for salmonids contained 60 to 80 percent fish products (based on Oregon moist pellet [OMP] and Abernathy open formula diets), while today's modern commercial salmonid diets contain only 30 to 40 percent or less of fish products, and this percentage continues to drop. It is clear that the use of alternatives has become cost-effective and this trend will continue. Research to reduce the barriers and cost to use alternatives needs to expand and keep in mind the environmental and product quality considerations that substitution and widespread use of those alternatives bring. Researchers in fish nutrition and alternative feedstuffs development should increase communication with scientists in the human health, agriculture, food sciences, bio-energy, aquaculture, animal physiology, and environmental sciences to help evaluate alternatives. This collaboration can help meet the goal of developing sustainable feeds for economically profitable, environmentally sound, and high health product aquaculture.